A STUDY IN THE PETROLOGY OF SEDIMENTARY ROCKS[1]

G. SHERBURNE ROGERS
U.S. Geological Survey, Washington, D.C.

INTRODUCTION

Since the introduction of the petrographic microscope about the middle of the last century a great mass of detailed information concerning the composition of rocks has been accumulated, but by far the greater part of this concerns igneous rocks alone. Metamorphic rocks have received their due share of attention, but sedimentary rocks have been almost entirely neglected. Thus, most university courses in petrology touch on the last-named class only in a more or less perfunctory way, and similarly in practical work the geologist generally confines the use of his microscope chiefly or entirely to the igneous rocks. This disparity is the more notable because of the fact that sedimentary rocks preponderate at the earth's surface, and while the study of their petrology does not seem to possess the fascination which attracts the students of igneous rocks, their areal importance is certainly such as to command attention. This paper is a preliminary and more or less tentative discussion of the value of microscopic work in the correlation of stratified rocks, with an example of an application recently made by the writer. Mr. D. F. Hewett, of the United States Geological Survey, has been working along similar lines, and the writer takes this opportunity of expressing his appreciation of Mr. Hewett's many valuable suggestions.

Sediments, by their very nature and the manner of their derivation, do not lend themselves readily to the taxonomic principles which we apply to igneous rocks, nor can their almost infinite variations be traced and interpreted as clearly. It is perhaps for this latter reason that geologists have in general been content to classify a rock as sandstone, or shale, or arkose, without attempting

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to inquire very closely into the proportions of its component minerals or the shape of their grains. Many sedimentary rocks, it is true, have been examined and described as lithologic types for educational purposes,[1] or because of some peculiarity in distribution or occurrence,[2] and there are a few instances in which they have been carefully studied for economic reasons,[3] but little work of a genetic character, directed upon the rock as part of a mass or formation rather than as a more or less fortuitous rock type, has been done.

THE IMPORTANT LINES OF RESEARCH ON SEDIMENTARY ROCKS

During the past decade attention has been directed to sedimentary rocks by the masterly studies of Johannes Walther in Germany and the amplification of his work in this country by Barrell, Grabau, and others. These geologists have, however, dealt almost entirely with the stratigraphic relations of the beds, and such structural features as cross-bedding, mud cracks, etc. In endeavoring to ascertain the manner of deposition of the rock, whether for example as a deep-sea deposit or a river sediment, a delta or playa lake, they have assigned somewhat minor importance to its petrology, considering chiefly its broader megascopic characters. Considerable work has also been done upon the transportation of sedimentary material by water and by wind[4], and the consideration of criteria by which the amount of such movement may be estimated. Thus W. H. Scherzer[5] has constructed a classification of sand grains based largely on their size, their degree of angularity and the amount of

[1] Such descriptions are given by Diller, *Bull. U.S. Geol. Survey No. 150*, 1898; by Harker, *Petrology for Students;* by Kemp, *Handbook of Rocks;* by Hatch and Rastall, *Petrology of the Sedimentary Rocks;* and by the authors of most of the other textbooks on lithology.

[2] See for example L. Cayeux, "Structure et classification des Gres et Quartzites," *Congres geol. internat. C.R.*, 10th Session, 1906, pp. 1211–22.

[3] See for example, C. B. Berkey, *Bull. New York State Mus., No. 146*, 1911, pp. 124–48.

[4] See for a summary, with very complete lists of references, E. E. Free, "The Movement of Soil Material by the Wind," *Bull. Bureau of Soils, U.S. Dept. Agric., No. 68*, 1911.

[5] "Recognition and Classification of Sand Grains," *Bull. Geol. Soc. Amer.* (XXI), 1910, 625–62.

their polish. Finally, while relatively little detailed study of the mineral composition has been made, we have a fairly definite idea of the minerals which commonly make up clastic rocks, and, in the case of feldspar at least, some conception of its genetic significance.

It is the belief of the writer that the three lines of research mentioned in the preceding paragraph, viz., upon the broad structural features, the shape of the grains, and the mineral character of the grains, may profitably be combined, and that the value of the results obtained by any one is greatly enhanced when considered in relation to the other two. The importance of a close study of the structural features of a clastic rock has been amply demonstrated by Barrell and others. The criteria given by Scherzer, when it is possible to apply them, are of similar value in determining the manner of deposition of the sediment and something of its history prior to deposition. Finally, the mineralogical composition of the rock, though in many cases having no apparent significance, is in others decidedly important. When a sandstone is made up practically entirely of quartz, as is the St. Peter sandstone, the significance of this fact is immediately recognized and taken into account in considering its history and derivation.[1] Thus, C. P. Berkey considers the St. Peter sandstone of eolian (sand dune) origin, because of the fact that it contains 98 to 99 per cent of quartz, largely in rounded grains of a nearly uniform size. Certain formations in the east, such as the Newark group, have been assigned a continental origin partly because of their arkosic character and red color, and this also illustrates a partial application of these principles. When the composition is less apparent to the naked eye, however, the importance of its determination may not be so evident; and very little is known of the exact mineral constituents of the great thickness of Cretaceous and Tertiary strata in the Great Plains and Rocky Mountain provinces.

Aside from the importance of such data in determining the history and origin of a rock they may in some cases have a distinct correlative value. Thus, in the instance of the Lebo shale member of the Fort Union formation described below, the writer was able to

[1] See "Paleogeography of St. Peter Time," *Bull. Geol. Soc. Amer.*, XVII (1906), 229–50.

correlate the strata by the varying, though generally small, amount of andesitic tuff or ash which it contains, the Lebo member at the type locality consisting chiefly of andesitic material. Similarly if a formation, or some particular stratum of a formation, were known to contain tourmaline, or a large amount of mica, or spherulitic glass, or some other distinctive constituent, this information might prove a valuable auxiliary in correlation to stratigraphic and paleontologic evidence. Though the instances last cited are doubtless uncommon it is probable that ash is rather widely distributed through the Cretaceous and Tertiary rocks of the west, and it may prove to be an aid to correlation in many cases. Moreover, even where conditions are not favorable to using the petrology in this way it is possible that it may throw light on the exact position of a doubtful formation boundary. Thus, D. E. Winchester, United States Geological Survey, believes that evidence of this kind may lead to fixing the lower limit of the Mesaverde formation in the Zuni Indian Reservation, New Mexico, where by reason of a lack of diagnostic fossils at the critical horizon the exact base of the formation cannot be otherwise located. The case of the Lebo shale described below furnishes a simple example of the value which petrologic evidence may have.

THE LEBO SHALE MEMBER OF THE FORT UNION FORMATION IN EASTERN MONTANA

General statement.—During the summer of 1911 the writer examined for the United States Geological Survey an area in eastern Montana known as the Little Sheep Mountain coal field[1] which extends about 60 miles westward from the town of Terry, on the Yellowstone River. In contiguous areas on the east and south the strata had been mapped as Fort Union and Lance.

About 850 feet of the upper or yellow strata of the Fort Union formation are exposed in the Little Sheep Mountain field, the age of these rocks being definitely established by paleontological evidence. The beds are made up of sandstone, sandy shale, and clay shale, generally soft and in many places incoherent, and commonly yellow

[1] G. S. Rogers, "Little Sheep Mountain Coal Field," *Bull. U.S. Geol. Survey No. 531*, 1913 (in press).

in color. The areas in which these beds are exposed are gently rolling prairies, or less commonly hills, with bare slopes. Directly across the river from Terry the yellow beds of the Fort Union formation are underlain by the Lance formation, of which only about 150 feet are exposed. This formation resembles the Fort Union in every way, except that there are perhaps more beds which are light gray in color instead of yellow. The contact between the two formations is marked by a coal bed (known as bed U) which is persistent through the eastern part of the field.

At a point about five miles west of Terry, however, the strata for 200 feet above coal bed U are dark gray in color and strikingly dissimilar to both the yellow Fort Union and the Lance (see Fig. 1). This dark gray member is composed of very irregularly deposited masses of shale with occasional arkose sandstones. Except for the numerous irregular and discontinuous layers of hard ferruginous concretions, and for a few fairly hard and generally massive sandstones, the beds are always soft and practically incoherent. The outcrop of this member, which traverses in a broad belt the entire field west of this locality, is characterized by the formation of badlands so rough in many places as to be almost impassable. This land is given over largely to grazing purposes, and even in the comparatively level creek bottoms it is very poor for agricultural purposes. The general sterility of this member, its tendency to form badlands, and its decidedly dark gray color all combine therefore to make it easily identifiable in the field.

For the reasons given below this mass of dark shale is believed to represent the Lebo shale member of the Fort Union formation. The Lebo was first described on Lebo creek in the vicinity of the Crazy Mountains,[1] about 175 miles west of the Little Sheep Mountain field. It is there interpreted as an outfingering of the Livingston formation,[2] which is composed of andesitic material, both detrital and tuffaceous, and which covers considerable areas west and south of the Crazy Mountains. This intercalated fan extends

[1] R. W. Stone and W. R. Calvert, "Stratigraphic Relations of the Livingston Formation of Montana," *Econ. Geology*, V, No. 6, September, 1910, p. 752 ff.

[2] See W. H. Weed, "The Laramie and the Overlying Livingston Formation in Montana," *Bull. U.S. Geol. Survey, No. 105*, 1893.

east to the Bull Mountains, about 50 miles west of the area under discussion, where it was mapped by C. T. Lupton.[1] Between this area and the Little Sheep Mountain field the beds are raised in a gentle anticline which exposes the Pierre shale, and the Fort Union and Lance are eroded, so that there is no way of actually tracing the Lebo member from the one field to the other.

Stratigraphic relations and structural features of the Lebo shale member.—The distinctive appearance of this member facilitated the recognition of the fact that it is wedge or fan-shaped. In the eastern part of T. 12 N., R. 51 E., directly opposite Terry, it is lacking. Coal bed U, which is taken as marking its base, is here

FIG. 1.—View of badlands in T. 12 N., R. 50 E., P.M., Montana, looking north; and showing the yellow beds of the Fort Union formation in the background overlying the gray Lebo shale member.

directly overlain by the yellow beds of the Fort Union and underlain by the light yellowish gray beds of the Lance. In the northeast quarter of sec. 9, T. 12 N., R. 51 E., there are about 12 feet of dark-gray shale above this coal bed. A half-mile to the west the strata above it are yellow and gray, alternating in about equal quantity; a mile farther west there are 200 feet or more of dark-gray material above it with only occasional beds of dirty yellow (see Fig. 1). In sec. 29 of T. 11 N., R. 50 E., seven miles southwest of the

[1] C. T. Lupton, "The Eastern Part of the Bull Mountain Field, Montana," *Bull. U.S. Geol. Survey, No. 431*, 1909, pp. 163–89.

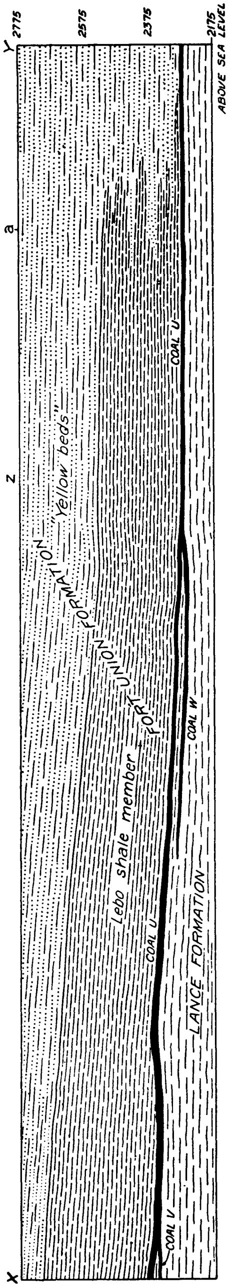

FIG. 2.—Diagram showing stratigraphic relations of Lebo shale member of Fort Union formation in Little Sheep Mountain coal field. Compiled from sections made along a line running 11 miles northeast from the mouth of Custer Creek (point *X*) to point *Z*; thence six miles east to a point opposite Terry (point *Y*). At point *a* a detailed section was made which showed the alternation of yellow and dark-gray strata as indicated.

last mentioned locality there are 250 feet of these dark shales between coal U and the yellow phase of the Fort Union; and on Custer Creek, seven miles farther southwest, about 340 feet. Beyond this there was no opportunity for measurement, and 20 miles farther west the coal which marks the base of the Lebo runs out of the district. The Lebo is therefore fan-shaped (see Fig. 2), of a thickness unknown in the western part of the field, but probably not greater than 350 or 400 feet; and reaching its eastern limit in this area in sec. 11, T. 12 N., R. 51 E., opposite Terry.

A noticeable structural feature of the Lebo member is the very irregular character of the beds, which change rapidly in a horizontal direction. A measured stratigraphic section represents the strata in one place only; at a distance of 1,000 feet on either side many of the beds change in color and often in texture. Scattered throughout the member are numerous lenses of a white and sandy material; these are commonly less than 2,000 feet in length and perhaps 60 feet in thickness, and are often only 200 feet long and 10 or 20 feet thick. In many cases they lie obliquely to the surrounding beds (Fig. 3) and are themselves strikingly cross-bedded (Fig. 4). The latter feature, together with

ripple-marks and mud cracks, is very common throughout the whole of the Lebo. The lenticular and irregular character of these strata extends to their coals as well, which are generally dirty, and, with the exception of bed U, of no great extent.

Petrologic evidence—mineralogical composition and character of grains.—The Lebo shale on the northeastern flank of the Crazy Mountains is described as a derivative of an andesite. Microscopic examination showed that certain facies are nearly pure tuffs, but that generally a considerable amount of plagioclase is present and

FIG. 3.—View in badlands on Custer Creek showing irregular character of the Lebo shale sediments, and the intercalation of lenses of white sandy clay which contains about 50 per cent andesitic ash, sec. 11, T. 11 N., R. 49 E., P.M., Montana.

that the whole is set in a fine chloritic groundmass. Fragments of hornblende and augite are also frequently found, and in places there is a considerable admixture of quartz. Eight thin sections were made of the more coherent members of the dark shale of the district discussed in this paper and in addition a number of sections of incoherent material were prepared without grinding; and all these were examined by the writer. Two of the thin sections were fine-grained dark gray shale, so fine in fact that the microscope revealed no recognizable grains. They seem to consist of kaolin stained

brown by iron oxide, and the shale may have been derived from nearly any kind of an igneous rock. Three of the sections were made from the grayish sandy lenticular material mentioned above, collected at two places about 10 miles apart in T. 9 N., Rs. 42 and 43 E. They are all decidedly tuffaceous in character and contain about 50 per cent of angular, subangular and rounded fragments of a brown volcanic glass, commonly more or less devitrified and altered. Quartz in small angular grains makes up about 40 per cent, and the remainder consists chiefly of kaolin and chlorite.

FIG. 4.—Cross-bedding in white sandy clay facies of the Lebo shale member, sec. 30, T. 11 N., R. 49 E., P.M., Montana.

Though the quartz indicates a considerable admixture of foreign material, this would be expected at a distance of 175 miles from the supposed source. One slide was made from a fine-grained, sandy, yellow-gray bed; this also revealed the presence of some volcanic glass, but the rock consisted chiefly of very small fragments of chloritic material with considerable quartz. Finally two sections of sandy shale partially baked by the action of a burning coal bed were examined. Their original character was, of course, largely destroyed, but fragments of a fresh green augite were identified in both of them. These descriptions hold also for the slides prepared

from the incoherent material; several were too fine-grained to permit of satisfactory identification, but the remainder contained varying quantities of glass, commonly badly altered. The sandy white material is thus derived directly from andesitic effusive material; all of the other rocks examined which were coarse enough to allow of study indicate a derivation, in large part at least, from a basic igneous rock; the shale is in general too fine to warrant an opinion as to its origin, but its evidence is not adverse. Furthermore, specimens of the yellow Fort Union above and of the Lance below were examined and all indicate a probable derivation from a much more siliceous rock; at least it may be said that they differ decidedly from the dark shale.

Owing to the fact that most of the important constituents of these rocks—glass and ferro-magnesian minerals—are prone to comparatively rapid alteration the evidence as to the shape of the grains in this instance cannot be satisfactorily obtained. The feldspar grains are in general nearly or quite fresh and are angular. The quartz is commonly in decidedly angular grains and only a few were noticed which were subangular or rounded. Similarly in the case of the glass it seems that the fresher the grain the more angular it is, some being found which were fairly fresh and distinctly angular. While these rocks are not favorable for a detailed study of the shape of the grains it may be said that they show the complete assortment as to size which characterizes Scherzer's aqueous type, but with the angularity which is regarded as diagnostic of the volcanic, glacial and residual types. Taking the mineral composition into account therefore they may be classified as aqueo-volcanic rocks.

Interpretation.—Because of this concurrence of the stratigraphic and petrologic evidence therefore it seems proper to corre ate these strata with the Lebo member. According to this hypothesis a large part of the material has been transported from the Crazy Mountains, although a considerable increment of foreign detritus has been received along the route. The striking cross-bedding and the decided lenticularity and lack of persistence of the beds argue for a fluvial origin, while the angularity of the grains themselves and their assortment as to size offer a similar suggestion and preclude the possibility of any long eolian transportation. It is possible that the

lenses of the white sandy tuffaceous material described above may represent the ancient stream courses. These lenses are numerous and generally of small size; in many cases they lie at a small angle across the strata and are themselves always strikingly cross-bedded (see Figs. 3 and 4). It would not be expected that recent erosion of the badland type would lay bare an old river course with its meanders for any great distance; the recent gulleys would cut across at all angles and the exposures of the old alluvium would pinch out abruptly. The shorter lenses would then represent an approximate cross-section of the old channel, while the longer ones might be interpreted as more or less complete approaches to a longitudinal section.

APPLICABILITY OF THESE PRINCIPLES

Lack of exactness in our present knowledge.—The application of the principles above outlined is naturally limited to certain formations, and is at the present time hampered by our comparatively small knowledge of the petrology of clastic rocks. The lack of detailed microscopic study is making itself felt in the deplorable looseness of our definitions of the types. A committee on the nomenclature of the more common types of sedimentary rocks was recently appointed in the United States Geological Survey, and in the course of a rather exhaustive search through the literature in an endeavor to find some basis for standardizing and delimiting the types in common use encountered a surprising discordance of opinion. Shale, clay, graywacke, arkose, argillite, etc., are differently defined in different books and in some cases not defined at all. With so little literature on the exact composition of sedimentary rocks and with the very basis of the lithology of these rocks in this condition it is difficult to say how great an aid microscopic work will prove in solving the problems of correlation or in reconstructing the conditions under which a sediment was laid down. At the present time it would seem that in many, if not most cases, such a study would have no immediate and practical value, but on the other hand, there are certainly many problems in which it might be used with direct advantage, as in the instance given above.

The lack of exactness in our present knowledge may be further illustrated by the following example, which represents another and

somewhat different application of these principles. The writer in the course of an examination of a portion of the ceded lands of the Crow Indian Reservation, Montana, during the past summer, followed the outcrop of a coal bed in the Lance formation for a distance of about thirty miles; and throughout this distance the bed contains a parting of material which closely resembles a brown carbonaceous sandstone. This parting varies only from three-fourths of an inch to $1\frac{1}{4}$ inches in thickness, and its constancy and persistence proved a decided aid in recognizing and correlating the coal bed. Such characters are exceptional in the Tertiary and Cretaceous continental deposits of the west, and the writer was prompted therefore to examine microscopically several specimens of the parting. In thin section this material proved to be, not a clastic sandstone as supposed, but to be a nearly pure aggregate of delicate mineral crystals, which undoubtedly formed *in situ*. The optical characters correspond to those of Leverrierite.[1] The mineral is now being more carefully examined and analyzed and the writer hopes to discuss it in a later paper.

It is apparent of course in this instance that the practical value of the small layer did not depend on microscopic examination, since use was made of it in correlation before its real nature was known. Microscopic study in this case merely served to explain its persistency and homegeneity, the characters which rendered it of value in the field, and to throw light on its origin and its relation to the coal bed and other strata. Moreover, the formation of such a pure mineral deposit in the midst of a heterogeneous mass of largely continental sediments is certainly of scientific interest; and if it is, as the writer is inclined to believe, not an uncommon development, but merely one which lack of previous petrologic work has held us in ignorance of, its bearing on the accumulation and alteration of sedimentary rocks is manifestly important.

Practical difficulties.—The microscopic study of sedimentary rocks is attended by certain practical difficulties which the writer can attempt only to suggest. In the first place the fineness of the material and the extent of its decomposition are important obstacles to the study of shale. Where the grain is not too uniformly small,

[1] First fully described by P. Termier, *Ann. d. Mines*, XVII (1890), 272.

washing or floatation may be used, thus removing the finely divided and thoroughly hydrated—perhaps colloidal—material. If more elaborate methods are desired, recourse may be had to the elutriator, the electro-magnet, heavy liquids, etc.[1] These methods of course destroy the proportions of the constituents, but facilitate the study of the features—assortment, angularity, and polish,—which are really important to the consideration of the rock from a genetic standpoint, and they will in many cases be the most expedient. On the other hand it seems probable that certain very fine-grained shales and clays are largely made up of colloidal material, which may prove to be homogeneous in composition and to have more or less distinct optical properties, and in such cases it may be desirable to study it as a whole without attempting at first to ascertain the character of the mineral particles from which it was derived.

Secondly, the question of field criteria for recognizing the particular rocks likely to prove critical presents itself, since it is obviously impossible to make and examine a complete collection of all the variations in a series. It is patent, of course, that very fine-grained rocks, since they do not respond satisfactorily to our present elementary methods of study, are less likely to prove helpful than the coarser-grained varieties; and on the other hand that the presence of uncommon constituents in very coarse sandstones and conglomerates can usually be recognized without the microscope. The writer must confess his inability to suggest any definite rule, however, and believes that from the nature of the case none can be framed. Such a question must be left largely to the field geologist.

Finally, it seems desirable that the geologist who studies the rocks in the field should be the one to examine them microscopically. The petrology of a sedimentary rock is in most cases of little or no significance except when considered in relation to the structural and stratigraphic features. Furthermore, its exact horizon is generally important and the relation of the stratum to those adjoining; and such data will, of course, be noted by the collector in any case.

[1] See F. H. Hatch and R. H. Rastall, *Petrology of the Sedimentary Rocks*, 1913, Appendix on the Systematic Examination of Loose Detrital Sediments, by T. Crook.

There are many minor points, however, which the field geologist remembers, but which were considered of too small importance to write down at the time, and which may yet derive an unexpected significance from the results of a simple petrologic study. When possible therefore, it is advantageous for the field man to examine his own material.

SUMMARY AND CONCLUSIONS

The amount of petrologic work done on sedimentary rocks, especially the more or less incoherent Cretaceous and Tertiary rocks of the West has been comparatively small, and most of the study made has been directed toward the rock as a rock type, rather than as a part of the rock mass or formation. Of late years attention has been directed to the broader structural features of clastic rocks and much information concerning the manner of deposition has been accumulated. It is believed that petrologic study of the mineral constitutents and the character of their grains will prove an important aid in determining the history of the rock, and that such study may also lead to facts of value in correlation and in the fixing of formation boundaries. An area of dark-gray shale near Terry, Montana, was correlated with the Lebo shale in the Bull Mountains to the west, largely by petrologic evidence. In this particular instance the determining constituent was andesitic ash, but in other cases the presence of other more or less distinctive constituents may be found significant and of value in correlation. There are two apparent difficulties confronting a study of this kind: first, those arising from the fact that many sedimentary rocks are made up of badly altered minerals occurring in grains too small for satisfactory examination; and second, the difficulty of choosing the proper rocks for detailed study. The fact that our definitions of sedimentary rock types are very vague and loose is in itself an argument for more petrologic study; and while it is not probable that this work will be found to have a very broad application to correlation, as in the one instance described, it still seems that it may prove an important auxiliary in that direction to the other lines of research at our command, and will in addition shed valuable light on the history of the rock.